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HIGH POWER TESTS OF BRAZELESS ACCELERATING STRUCTURES

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Abstract

A typical accelerating structure is a set of copper resonators brazed together. This multi-step process is expensive and time consuming. In an effort to optimize production process for rapid prototyping and overall reduction of accelerator cost we developed a split block brazeless accelerating structure. In such structure the vacuum is sealed by the use of knife edges, similar to an industry standard conflat technology. In this paper we present high power tests of several different brazeless structures. First, an inexpensive 1 MeV accelerator powered by radar magnetron. Second, a high gradient power extractor tested at Argonne Wakefield Accelerator Facility. In this experiment a high charge electron beam generated a 180 MW peak power pulse. Finally, we report on high power testing of a brazeless x-band accelerating structure at SLAC.

INTRODUCTION

Accelerating structures designed for X-band and higher frequencies have relatively small volume. For this reason they can be fabricated in a form of split block [1] out of two halves. These two blocks can be welded or brazed together. Alternatively this design can be brazeless, when two halves are joined via viton gasket or a stainless steel joining part with knife edges, similar to conflat design.

Brazeless technology became of high interest to high gradient accelerator community. One argument for is that brazeless structure having not gone through thermal treatment cycle is not annealed, i.e. copper stays hard. Conditioning and breakdown studies at CLIC and SLAC show that hard copper structure can tolerate higher field gradients than annealed one. With the new brazeless split-block design high gradient applications open up for low budget prototyping.

In this paper we report on the design and testing of a power extractor at the AWA (Argonne Wakefield Accelerator).

HIGH GRADIENT STRUCTURE DESIGN

We have designed this high gradient structure and currently looking for a vendor to fabricate it. Brazeless technology allows the design to be flexible. Some unusual possibilities arise, like power extractor consisting of individual resonators with each having it's own waveguide outcoupling. In this design individual resonators are not coupled to each other and their shut impedance can be maximized. Overcoupling can be utilized to minimize the quality factor of the resonator for short pulse and high peak power production. Such structure is very robust because each resonator can be individually tuned. Low loaded quality factor allows for large play in the admissible resonant frequency for each resonator. Waveguide from each resonator eventually combine together by a series of waveguide combiners. Timing for RF pulses from different waveguides to be combined coherently requires 100 µm tolerance fabrication which is by current standards is easy.

The early design of a set of individual resonators had been improved for a final prototyping. We added more resonators to facilitate stronger deceleration of the electron beam hence increasing the power output.

In final design we have a set of double-cell resonators (Fig. 1a, b and c) with a single waveguide output. This presents a compromise of relatively easy design and tuning combined with a simple RF output and pulse combiner (Fig. 1b). Also loaded quality factor of a double-cell resonator can still be low enough to produce a short RF pulse. This structure should produce a 10 ns – 0.9 GW RF pulse at 11.7 GHz frequency when driven by a train of eight 50 nC bunches (Fig. 1d). Such structures can be used to power a two beam accelerator for GeV machines like free electron lasers (ex MaRIE FEL). Figure 2 shows an engineering design, a brazeless split-block realization of such structure.

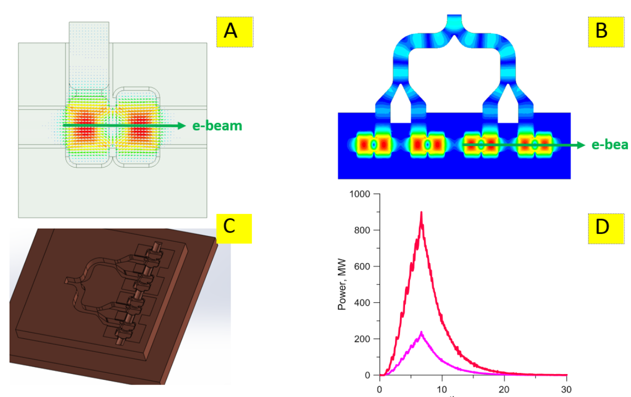

Figure 1: Final design of the power extractor. A) Double-cell design. B) Power extractor and waveguide combiner field distribution. C) Split block engineering: bottom half of the assembly. D) Simulations of power extraction – sub-GW peak power is projected.

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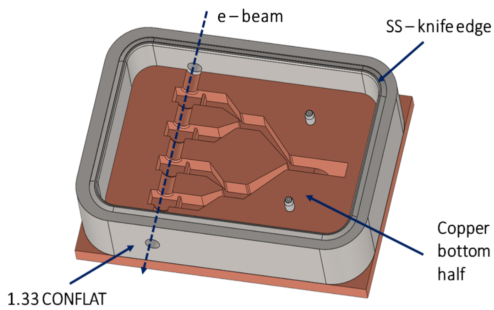

Figure 2: The engineering design of the brazeless split block structure.

FABRICATION AND BENCH TESTING

The structure has been fabricated via high precision CNC. The finished parts are shown in Fig. 3.

Figure 3: Finished parts of the brazeless split block structure.

The structure was cleaned and pre-assembled for the bench measurement. The measured frequency is 11.721 GHz which is 21MHz higher than the 9th harmoic frequency of the AWA drive beam reptetion rate, 1.3 GHz, but it is still acceptable via the fine adjustment of the bunchlets spacing. The field profile from the bead pull measurement is shown in Fig. 4. The structure is designed to have four RF isolated cell couples which then are combined through a waveguide combining system to extract rf power. Around 20% field inbanlance is shown in the measurement. However, by nature of beam power extractor, the output power at the waveguide opening is the combination effect of entire structure. The field imbalance only affects the local field at each cell. Therefore, we decided not to tune the structure.

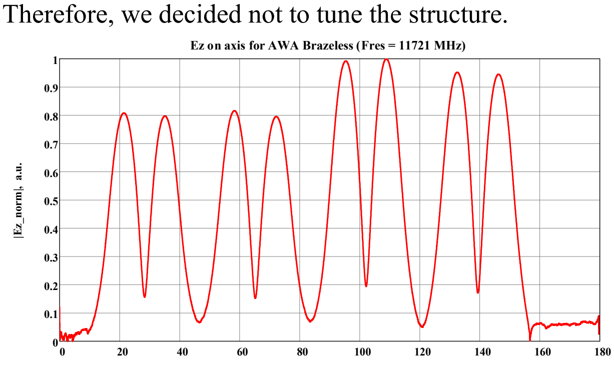

Figure 4: The measured field profile by a beadpull test of the split block.

HIGH POWER TEST AT THE AWA

The beam experiment was carried out at the AWA (Argonne Wakefield Accelerator) 70 MeV drive beamline on October 2020. The setup is shown in Fig. 5. The high charge beam went through the structure and the generated RF power was measured through a waveguide bidirectional coupler. The rf power was finally dumped to the high power RF load. The beam was delivered to the structure with 100% transmisstion through the structure based on the ICT measurement before and after the structure. The highest beam current was a train of 8 bunches up to 48 nC per bunch. The measurement results are plotted in Fig. 6. About 180 MW of rf power was measured and no obvious breakdown events were detected. The final examination will be conducted after the structure can be moved out of the AWA bunker (the structure is still slightly activated). As shown in Fig. 6, the measured RF signal matches very well with the simulation. It should be pointed out that the filling time of the split-block structure, a flat top of the rf pulse had not been reached with a train of 8 bunches. A longer drive bunch train (more bunches in the train) is needed for a longer flat top rf pulse.

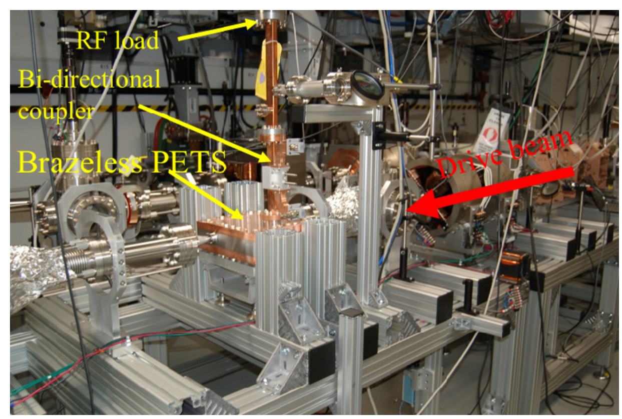

Figure 5: Experimental setup of the high power structure test at the AWA drive beamline.

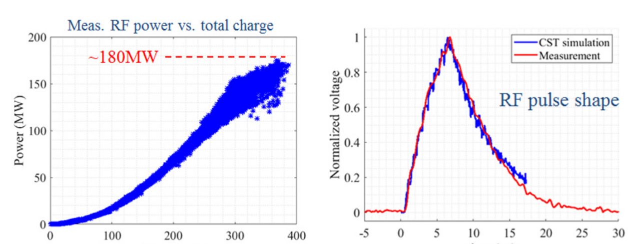

Figure 6: Left: The measured RF power at output of the split block; Right: Comparison of the measured and simulated RF pulse.

In the high power experiment we were not able to reach the expected RF power of about 800 MW (for a 8-bunch train of 48 nC charges).

This split-block structure is the first brazeless RF power extractor tested at AWA drive beamline. The structure was cleaned and assembled at the AWA facility

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to meet the UHV requirments. The final assembly was leak checked and bench measured again before the installation on the beamline. The measured frequency was 11.67 GHz, 30 MHz lower than the targeted frequency. As it turns out such a deviation results in a significant power decrease. The simulation on Fig. 7 shows around 4 times reduction of the generated rf power due to the mismatched the RF group signal delay among different cells. The simulated voltage signals at the output port under two different senarios are presented in Fig. 7. The 50 nC of single bunch and a train of 8 bunches with 1.3 GHz microbunch repetition rate were used for the simulation. The structure frequency was changed by enlarging the vertical size of the cells (eqv. to add a small gap between two split halves). ~800 MW would have been obtained at the targeted 11.7 GHz, but less than 200 MW at 11.67 GHz, which is matched perfectly with the measurement in the final beam test.

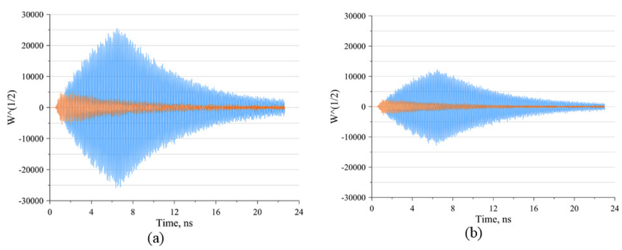

Figure 7: The simulated RF output pulse of RBA-AWA at the targeted frequency 11.7 GHz (a); and measured frequency 11.67 GHz (b). The orange color signal represents the single drive bunch case, and the blue signal is the output of a drive bunch train of 8 bunches.

Nevertheless, a test of brazeless power extractor was considered a success. Fast turnaround time and design flexibility attract a lot of interest to brazeless split block accelerating structures.

ACKNOWLEDGEMENT

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